Variable Stars in the Field of Young Open Cluster NGC 581

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ABSTRACT

We present results of the search for variable stars in the field of young open cluster NGC 581. Based on 19 nights of observations, 6 new variable stars were discovered. Two of them turned out to be eclipsing binary systems. Another two detected variable stars are most probably of γ Dor type. During our observations one of the known Be stars located in our field of view showed irregular variations of brightness, typical for this class of stars. The sixth variable star is a pulsating red giant.

Stars: variables: general – open clusters and associations: individual: NGC 581

1 Introduction

Searches for variable stars in star clusters are very useful, because both variable stars and clusters are important sources of information on fundamental problems of stellar astrophysics. Variable stars which belong to cluster are especially well suited for studies of stellar dynamics and evolution. From their observations also many information on cluster age, distance and chemical composition may be obtained.

Our search is part of the long term project, aiming at systematic search for variable stars in open clusters initiated at the Warsaw University Observatory. Observations were conducted with both: 0.6 m telescope located at the Ostrowik Station near Warsaw and 1.3 m Warsaw telescope, located in the Las Campanas Observatory (LCO), Chile in the course of the OGLE project (Udalski, Kubiak and Szymański 1997). At the Ostrowik

Observatory four Northern Hemisphere clusters were monitored: NGC 654, NGC 663, IC 4996, NGC 659 (Pietrzyński 1996abcd, 1997, Pietrzyński 2001) and in total 21 variable stars were discovered. Southern Hemisphere clusters were monitored from the LCO observatory and 59 new variable stars were discovered in the fields of two clusters: NGC 5999 and NGC 5381 (Pietrzyński *et al.* 1997, 1998). In this paper we present results of the search for variable stars in the field of another, Northern Hemisphere open cluster: NGC 581.

The cluster was cataloged already in XIX century by Messier (1850) with number 103. Later it was observed by Alter (1940), who first derived its distance. Since then NGC 581 has been a subject of several investigations, including photographic UBV studies of Hoag *et al.* (1961), McCouskey and Houk (1964), Moffat (1972), Sagar and Joshi (1978), and RGU study by Steppe (1974). Recently, Phelps and Janes (1994), based on precise BV CCD photometry, derived the distance and the age of this cluster of about 2690 pc and 22 Myr, respectively.

2 Observations

Presented data were collected in 1999 during 19 nights at the Ostrowik Station of the Warsaw University Observatory. The 0.6 m Zeiss reflector equipped with 512×512 pixel CCD detector was used. The scale of 0.74 arcsec/pixel corresponds to the total field of view of about 6.5×6.5 arcmin. The gain and readout noise were about 9.4 e^-/ADU and 13.7 e^-, respectively. More details about the instrumental system can be found in Udalski and Pych (1992).

Observations were performed through the Cousins I filter with exposure times of 10 sec and sequence of 3×120 sec and through the V filter with exposure time of 120 sec. The map of the observed region is shown in Fig. 1.

All images were de-biased, dark current subtracted and flat-fielded using the IRAF* package. Sequences of the three 120 sec images were then co-added in the following way, adopting the software from the Difference Image Analysis (Woźniak 2000). First, the shifts between all three frames were calculated and every frame was resampled into the coordinates of the first one. Then, the frames were summed using the IRAF package. This

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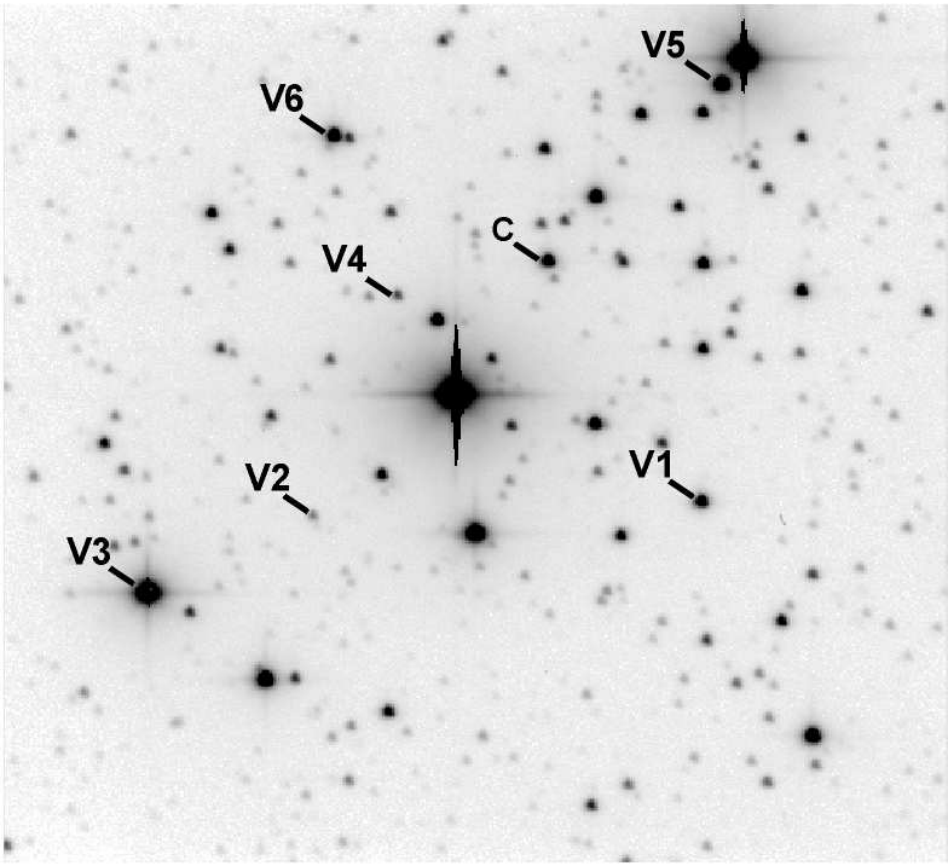

Fig. 1. Map of NGC 581 based on a frame taken with 120 sec exposure through the I filter. The field of view is about 6.5×6.5 arcmin. North is up and East to the left. V1-V6 mark detected variable stars. C points the comparison star.

operation changed depth of our photometry from about 18 mag to about 19 mag in the I filter.

Profile photometry was determined using DAOPHOT and ALLSTAR programs independently for all sets of data: 10 sec, 120 sec and 3×120 sec in the I filter and 120 sec in the V filter. The stellar point spread function (PSF) was obtained from an average of 6 visually selected isolated stars. Table 1 contains information on total number of frames, mean error returned by DAOPHOT, approximate brightness of faintest stars and number of objects in database of every set of data.

In order to create databases, images obtained at the best seeing condi-

T a b l e 1

Information on analyzed images of NGC 581

filter (exp.time)	number of frames	DAOPHOT error [mag]	mag_{lim} [mag]	number of objects
V (120s)	74	0.06	18	151
I (10s)	231	0.02	14	69
I (120s)	697	0.05	18	282
I (3×120s)	225	0.04	19	325

tions for every set of data were selected. Then, the master list with positions of all stars from the "template" image was prepared. Positions of stars from the remaining frames were compared with this list and for every star from the master list individual file with photometry was created. After subtraction of comparison star for all detected stars periodograms based on the AoV method (Schwarzenberg-Czerny 1989) were calculated and searched for significant maxima. Independently all stars were also examined visually for variability. This procedure was repeated for every set of data. In databases of stars obtained from 120 sec and combined 3×120 sec exposures made in I filter we found five variable stars. Another star, which was saturated on longer exposure frames, was found to be variable in 10 sec I filter database. All variables, except for the saturated one, were confirmed in the V filter database.

Magnitudes of all stars were transformed from our instrumental system to photometry obtained by Phelps and Janes (1994), taken from the database of Galactic open clusters BDA (Mermilliod 1995). Common stars were identified visually. Then, coefficients of transformations were calculated using the least squares solution. Transformation equations and coefficients for summed I filter images and 120 sec exposure V filter are:

$$\begin{aligned} V &= 0.9929 \cdot v - 0.0632 \cdot (v-i) - 0.1493, \\ V-I &= 0.7874 \cdot (v-i) - 0.6911, \\ I &= 1.0210 \cdot i + 0.0939 \cdot (v-i) + 0.2996. \end{aligned}$$

Accuracy of transformations was about 0.04 mag for magnitudes in V and I, and about 0.03 for $V-I$ color.

3 Variable Stars

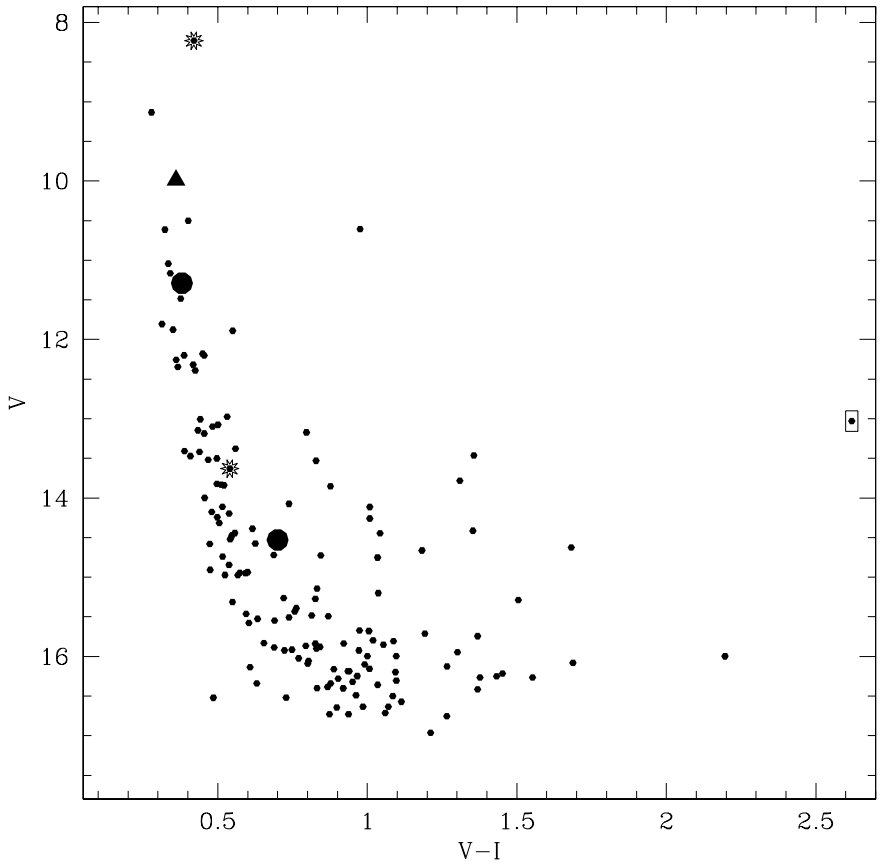

Fig. 2. Color-magnitude diagram of the cluster NGC 581. Circles denotes detected eclipsing systems, triangle – photometrically variable Be star, square – pulsating red giant star. Stars mark γ Dor candidates.

In total six variable stars were found. Fig. 2 shows location of detected variable stars in *V vs. V–I* color-magnitude diagram (CMD). Table 2 contains their description. The following columns contain: designations of variable stars, their numbers in BDA database (Mermilliod 1995), brightness in *V* and *I* filter (for phase 0.5 for V1 and V2, for HJD–2 450 000 of 1432.5 for V5 and mean brightness for V3, V4 and V6), times of primary minima (for V1 and V2) or maxima (for V3, V4 and V6), derived period (if exists) and

observed amplitudes (for V1 amplitudes of primary and secondary minima are given).

T a b l e 2

Variable stars and the comparison star in the field of NGC 581

Star	Number in BDA	V [mag]	I [mag]	HJD – 2450000.0	Period [d]	Amplitude [mag]
V1	42	11.29	10.91	1427.8223	4.5020?	0.20/0.11
V2	148	14.53	13.83	1426.7624	1.6828?	0.21
V3	144	8.23	7.81	1427.4674	0.6260	0.11
V4	121	13.63	13.09	1427.0831	0.6751	0.11
V5	178†	9.99	9.63	–	–	0.44
V6	7089	13.03	10.41	1426.3096	1.1494	0.08
C	1227	11.28	10.83	–	–	–

3.1 Eclipsing Binary Stars

Light curves of two newly discovered detached eclipsing binary systems: V1 and V2, are shown in Figs. 3 and 4.

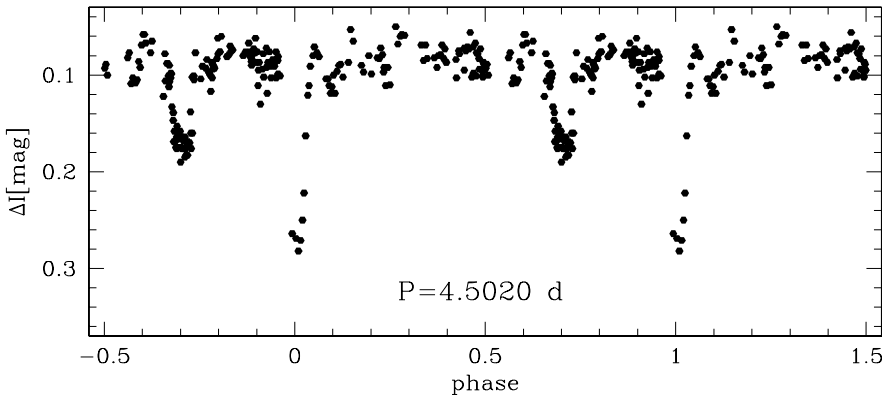

Fig. 3. Light curve of V1. ΔI indicates the difference variable minus comparison.

Light curve of variable V1, phased with the period of 4.5020 days suggests large eccentricity of the system orbit. Because of scarceness of our data this

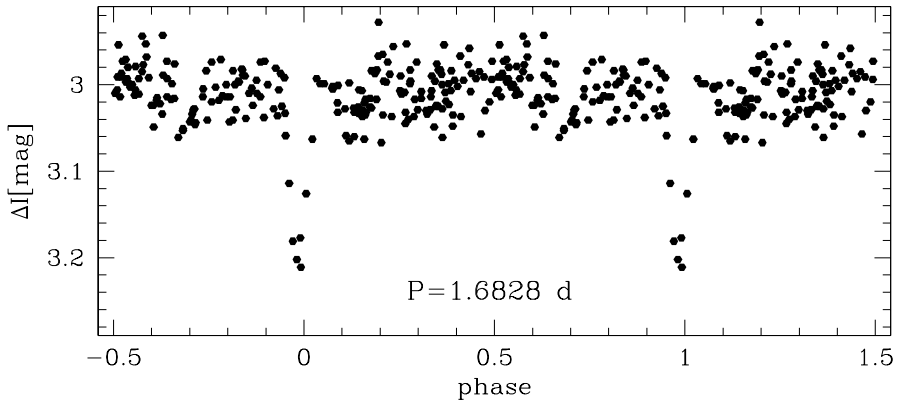

Fig. 4. Light curve of V2. ΔI indicates the difference variable minus comparison.

period is still preliminary. Observations can also be phased with the period of 6.006 days. The light curve of V1 phased with this period does not show eccentricity. This stars was classified by Hoag and Applequist (1965) to have the spectral type of B2 V, what is consistent with its position in our CMD (see Fig. 2).

Period of another eclipsing binary star (V2) is also very preliminary. Some other periods are not excluded, but the chosen one (1.6828 d) seems to be the best.

Positions of both detached eclipsing systems in the CMD (Fig. 2) support their cluster membership. Additionally, Sanner *et al.* (1999) confirms cluster membership of star V2 based on the study of proper motions.

For better determination of the periods of both stars, V1 and V2, further observations are recommended.

3.2 γ Dor Candidates

In Fig. 5 light curve a pulsating variable star, designated as V3 is presented. This star was previously investigated for its cluster membership by Sanner *et al.* (1999) (their star B). The derived proper motion turned out to be very different than the proper motion of the cluster. The spectral type of V3 is either A9 V (Sowell 1987) or F0 V (Jensen 1981). The only known pulsating variable stars of this type are stars of γ Dor type (*e.g.*, Kaye *et al.* 1999). The period of V3, equal to 0.6260 days, is also typical for this type of variable stars. Liu *et al.* (1989) noted variations of radial velocity of V3. We conclude then that star V3 is most probably a background γ Dor star.

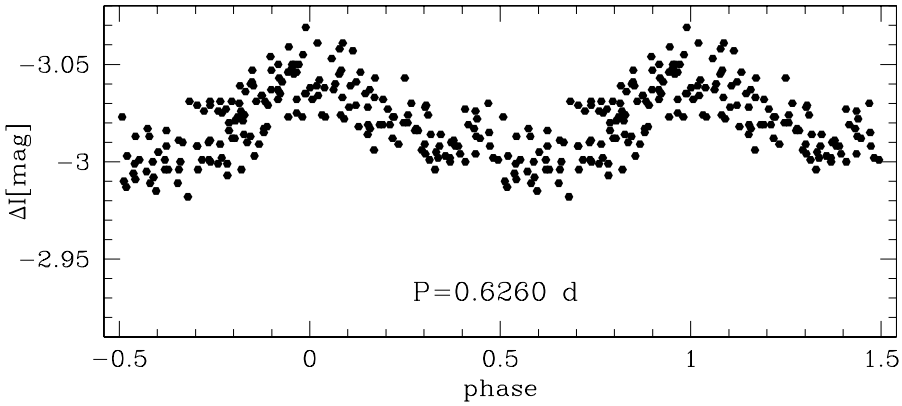

Fig. 5. Light curve of V3. ΔI indicates the difference variable minus comparison.

In Fig. 6 light curve of another γ Dor candidate, V4 is displayed. This star is a member of NGC 581 (Sanner *et al.* 1999), what is in agreement with its location in the color-magnitude diagram. The most probable period of this star is 0.6751 days. When the same data are phased with the two times longer period the shape of its light curve is similar to the light curves of W UMa stars. Taking into account the young age of the cluster we can exclude this hypothesis. Unfortunately the spectral type of this star is not available. Its position in the CMD suggests the spectral type of late B or early A. This star can be then either a Slowly Pulsating B star (SPB, Waelkens 1991) or a γ Dor variable. SPB stars are known to be multi-period variables, so we performed check for multiperiodicity. No other periods except for 0.6751 days, were found. It seems therefore that this object is more likely another γ Dor type star, found in the field in NGC 581. Also the brightness of V4 compared to other γ Dor candidates, found in our previous work in NGC 659 (Pietrzyński *et al.* 2001), seems to be similar, when the difference of 0.5 mag in distance modulus of both clusters is taken into account. Spectral observations of this star would help in distinguishing between these possibilities.

3.3 Miscellaneous Stars

In the field of NGC 581 there are four known Be stars (Schild and Romanishin 1976, Mermilliod 1982, Phelps and Janes 1994). Two of them were monitored during our observations. Star with BDA number 49, did not

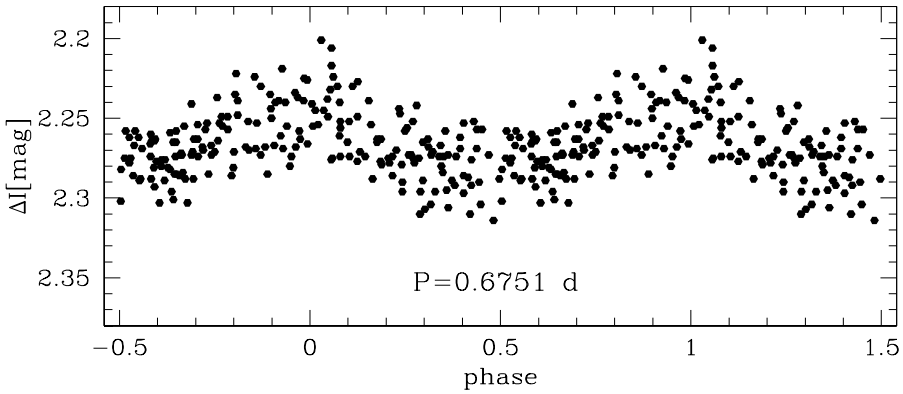

Fig. 6. Light curve of V4. ΔI indicates the difference variable minus comparison.

show any brightness variability. Light curve of another Be star, designed as V5 is presented in Fig. 7. Our data are too scarce to allow any conclusion about possible periodicity of this star, but its behavior (irregular changes of the brightness by a couple of tenths of magnitude, over the relatively long period of time) is typical for Be type star. Its position in the CMD is consistent with the B spectral type of this star. Unfortunately because of the very close proximity of the very bright star (of $V = 7.26$ mag) and low accuracy of previously derived coordinates, it is not easy to cross-identify this star with the BDA database. Most probably our star designated as V5 corresponds to an object with the number 178 in BDA. This star was discovered to be a Be star (*e.g.*, Schild and Romanishin 1976, Mermilliod 1982). Also the brightness and color of star 178 seems to be similar to V5, (*e.g.*, Burnichon 1976 gives $V = 9.90$ mag and $B-V = 0.24$ mag, Purgathofer (1964) gives $V = 10.04$ mag and $B-V = 0.19$ mag, Sagar and Joshi (1978) give $V = 10.09$ mag, $B-V = -0.01$ mag, Hoag *et al.* (1961) give $V = 9.35$ mag, $B-V = -0.29$ mag). One can also suspect that relatively large differences in brightness determinations of this star obtained in the past were due to intrinsic photometric variations of this object.

Light curve of another variable, V6, found in the field of NGC 581 is presented in Fig. 8. Brightness of this star varies with the period of 1.1494 days. However, the period two times longer cannot be excluded. Because V6 is very red with the mean $V-I$ color equal to 2.61 mag we suspect that, it is a pulsating red giant star.

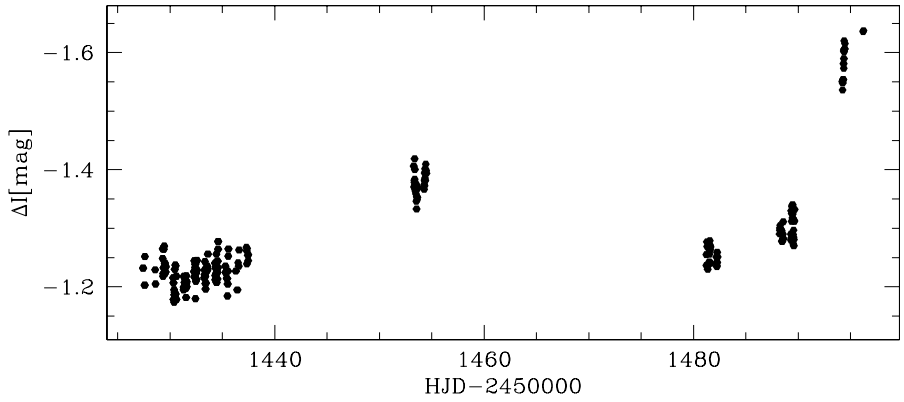

Fig. 7. Light curve of V5. ΔI indicates the difference variable minus comparison.

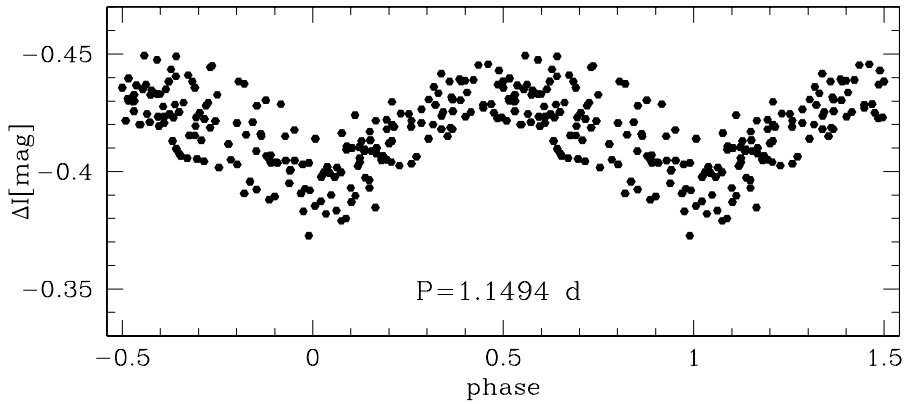

Fig. 8. Light curve of V6. ΔI indicates the difference variable minus comparison.

4 Summary

We have presented results of a photometric search for variable stars in the field of young open cluster NGC 581. We have found six variable stars based on observations collected during 19 nights. Two detached eclipsing binaries were found in the field of NGC 581. Unfortunately, because of the scarceness of our data the periods derived for these stars are only preliminary. Stars designated as V3 and V4 are probably new γ Dor candidates. Variable star designated as V5 seems to be the previously known Be star. Irregular changes of its brightness detected during our observations are typical for this class of stars. Another known Be star from NGC 581 was observed,

but we did not notice any changes of brightness. Star V6 is most likely a pulsating red giant star.

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